Revisiting the Need of Improved Stoves: Estimating Health, Time and Carbon Benefits

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Abstract

Indoor air pollution (IAP), especially through the smoke released when burning solid biomass fuel for cooking, is a major environmental health problem in Nepal. About 85 percent of Nepalese households are dependent on solid biomass fuels for cooking energy. Among households using such fuels, most cook in poorly ventilated kitchens using inefficient stoves, leading to indoor air pollution and consequently health problems. While there are successful technologies/interventions which help to mitigate IAP, due to lack of evidence on the economic viability of such interventions, they have not been adequately scaled up. This study generates some evidence on the costs and benefits of a particular indoor air pollution control initiative. Based on a survey of 400 households in Rasuwa district, Nepal, the study finds that stove improvements and a smokehood in the kitchen can reduce the consumption of fuel, improve air quality and reduce the health costs borne by households. Such local interventions can also contribute to mitigating global problems such as the release of green house gases through biomass burning. This study finds that the average indoor air pollution level in traditional stove user households is 15 times higher than the recommended safe level which inevitably leads to high health expenditures. The benefit-cost analysis suggests that the investment in IAP mitigating intervention is viable from both the household and societal perspectives.

Key words: Indoor air pollution, Cooking energy, Solid biomass fuel, Nepal, Health problems, Green House Gases, Cost Benefit Analysis

Revisiting the Need for Improved Stoves: Estimating Health, Time and Carbon Benefits

Min Bikram Malla Thakuri

1. Introduction

Indoor air pollution (IAP), especially smoke generated from burning solid biomass fuel in kitchens, is a major environmental health issue in Nepal. Some 85 percent of Nepalese households are dependent on biomass fuels for cooking energy (CBS, 2004). Biomass fuels such as animal dung, crop residues and wood, which are considered the most polluting fuels, lie at the bottom of the energy ladder, and are used mostly by the very poor people. In Nepal these fuels are typically burnt in open fires or poorly functioning stoves and more often than not indoors with inadequate ventilation creating a dangerous cocktail of hundreds of pollutants to which women and young children are exposed on a daily basis. According to the World Health Organization (WHO, 2007) estimates, IAP from solid fuel burning was responsible for the deaths of 7,500 people, 204,400 Disability-Adjusted Live Year (DALYs) loss and 2.7 percent of the national burden of diseases in Nepal in 2002. According to Nepal Demographic and Health Survey (NDHS) 2006, acute respiratory infection (ARI) has contributed to 23 percent of the total deaths in the year 2006 among children below five years of age. In Nepal, acute lower respiratory infections (ALRI), Chronic Obstructive Pulmonary Disease (COPD) and Tuberculosis are among the top 10 causes of death. There is strong evidence to suggest the role of IAP in the occurrence of such illnesses. Responses to such illnesses so far have focused on treatment rather than on prevention. However, an increasing number of international health professionals and policy makers are beginning to recognize indoor air pollution as a serious problem. While much work has been done on improving stove design, their focus has been on energy efficiency and fuel saving; lifting the burden on women's time and effort; and saving forests. Attention has turned to the issue of indoor air pollution and health only in the last few years (ITDG, 2004).

The economic valuation of health and environmental interventions is becoming increasingly important (WHO, 2004). In light of limited funding, such valuations can provide an important tool to: (i) demonstrate the economic returns of investments in intervention; (ii) compare the effectiveness of one intervention against another; and (iii) help policy-makers decide on how to allocate their limited resources. With household energy playing such a central role in people's lives, interventions to reduce indoor air pollution could potentially deliver a wide range of benefits in the areas of health, environment and poverty reduction.

A number of technologies and alternatives are available to solve the indoor air pollution problem. However, due to lack of information on the costs and benefits of such technologies, wide-scale adoption is not taking place at a satisfactory pace in Nepal. Given this information gap, our research aim was to analyze the viability of investment in smoke alleviating products. To meet this goal, we administered a survey in 400 households (HHs) in Rasuwa district, Nepal. The results of the analysis show that the average indoor air pollution level in traditional stove user households is 15 times higher than the recommended safe level. The benefit-cost analysis suggests that investment in IAP mitigating interventions is viable from a household as well as a societal point of view.

2. Indoor Air Pollution Problem in Developing Countries – A Review

More than three billion people worldwide depend on solid fuels, including biomass (i.e., wood, dung and agriculture residues) and coal, to meet their basic energy needs such as cooking, boiling water and heating (WHO, 2006). However, inefficient burning of biomass fuel creates a dangerous cocktail of hundreds of pollutants. In general, people in developing countries use solid fuels because of their availability and affordability. Since the use of poor quality fuels decreases with development, the least developed areas are the most likely to experience the highest levels of indoor air pollution (Smith, 1993). In general, cook-stove efficiency[1] is 20%, 30%, 50%, and 70% respectively for wood, charcoal, kerosene, and Liquid Petroleum Gas (LPG) stoves. Such fuel efficiency seems to be inversely correlated with the amount of health damaging pollutants it emits per joule of energy (Smith, 1994).

There is abundant evidence supporting the relationship between IAP and health problems such as acute respiratory infections, chronic obstructive pulmonary disease, and lung cancer in women (Smith, 1999; Ezzeti and Kammen, 2001). Inhaling indoor smoke doubles the risk of pneumonia and other acute infections of the lower respiratory tract among children under five years of age. Women exposed to indoor smoke are three times more likely to suffer from chronic obstructive pulmonary diseases (COPD), such as chronic bronchitis or emphysema, than women who cook with electricity, gas or other cleaner fuels. Use of coal doubles the risk of lung cancer, particularly among women. Moreover, some studies have linked exposure to indoor smoke to asthma, cataracts, tuberculosis, adverse pregnancy outcomes, in particular low birth weight, ischaemic heart disease, interstitial lung disease, and nasopharyngeal and laryngeal cancers. Globally, IAP is responsible for 1.6 million deaths annually and 2.7 percent of the global burden of disease (WHO, 2006).

As women cook and small children (usually below five years of age) spend most of their time in the kitchen area with their mothers, these two groups are the most vulnerable to indoor air pollution. Smoke inside the house is one of the world's leading child killers, claiming nearly one million children's lives each year (ITDG, 2004). A Gambian study (Schwela, 1997) found that children under the age of five, who were carried on their mother's backs during cooking (in smoky cooking huts), increased their risk of developing Acute Respiratory Infection (ARI) up to six times. This was significantly higher than if their parents smoked. Qin *et al.* (1991) and Peng *et al.* (1998) find that more women and children from families using coal for household energy suffer from respiratory symptoms than those from families using natural gas. There is also evidence to support possible associations of IAP with tuberculosis, blindness and prenatal effects (Smith, 1999). The smoke from biomass combustion is also associated with reduced birth weight (Misra *et al.,* 2004). Pokharel *et al.* (2005) establish a strong correlation between the use of solid fuel in traditional stoves and the increased risk of cataract in women who do the cooking. Pandey (1984) found a significant correlation between the prevalence of chronic bronchitis and exposure to domestic smoke pollution in rural Nepal. Time loss in firewood collection is also very high in Nepal. On average, a household collects 18.3 *bharis* (i.e., headloads) or bundles of firewood per capita per year. On average, a household spends 5.01 hours for collecting one *bhari* firewood (Baland *et al.,* 2008).

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[1] *Stove efficiency is the capacity of that stove in terms of combustion of fuel. In other word capacity of the stove to change the energy from fuel to heat energy is related with burning efficiency.*

Studies (ITDG, 2004, for example) suggest that IAP is strongly associated with income level. It is the poor who rely on the lower grades of fuel and have the least access to cleaner technologies. Millions of people would lead a healthier life if their exposure to lethal levels of smoke were reduced. The most effective interventions and the most beneficial to the user and society as a whole would be a shift from wood or charcoal to kerosene, LPG, biogas or grid electricity for cooking energy. Other more progressive alternatives may be ethanol (gel) fuel and biomass gasification (Ballard-Tremeer and Mathee, 2000). But the current energy use and availability trends in developing countries indicate that solid fuel will continue to dominate fuel use in developing countries for the next several years. However, even taking this fact into consideration, there are possible interventions that could potentially reduce exposure to indoor air pollution. These interventions can be classified under three headings (Ballard-Tremeer and Mathee, 2000): source (fuel, type of stove); living environment (housing, ventilation); and user behaviour (fuel drying, protection of child).

Bluffstone (1998) suggests that for a developing country like Nepal, where agriculture is the major form of livelihood and villagers depend on forests for important economic inputs, interim demand-side policies should be seriously considered to protect forests. According to him, promoting improved stoves is a more efficient and equitable instrument than subsidizing the major alternative fuel (kerosene) in order to reduce firewood demand. He therefore emphasizes provision of subsidies for improved stoves.

A Guatemalan study (McCracken and Smith, 1998) shows that the Plancha stove (an improved stove made of cast concrete) emits 87% less $PM_{2.5}$[2] and 91% less CO (carbon monoxide) per kJ of useful heat delivered as compared to an open fire during the water boiling test. Dasgupta *et al.* (2004) find the ventilation factor to have a strong effect on the level of particulate matter (PM). The study of Pitt *et al.* (2006) in Bangladesh suggests that chimneys are significantly effective in reducing the health impacts of stove proximity when biomass fuels are in use. The study also reports that proximity to stoves adversely affects the respiratory health of women and young children.

In order to evaluate the effectiveness of interventions, it is important to value the changes that occur as a result of stoves and other interventions. A big part of this is valuing the health impacts. There are many studies already on valuing the health effects of outdoor air pollution (e.g., Cropper *et al.,* 1997; Ostro *et al.,* 1998; Alberini *et al.,* 2000; Krupnick *et al.,* 1996, 1999, 2000; Murty *et al.,* 2003; and Gupta, 2006). But valuation of IAP is a relatively new area of research. Larson and Rosen (2000) have done some work on this subject while Habermehl (2007) analyses the benefits and costs of the Rocket Lorena Stove dissemination programme in Uganda. Further, WHO reports by Hutton, Rehfuess, (2006) and Hutton *et al.,* (2006) describe the methods and data sources that form the basis for the cost benefit analyses of household energy and health interventions and present the results for eight intervention scenarios of relevance to energy policy in the context of Millennium Development Goals. The report concludes that the health and productivity gains far outweigh the overall cost of interventions to alleviate kitchen smoke.

[2] *These are very small particles less than 2.5 micrometers in diameter that can enter and penetrate the lungs.*

According to Bruce (2000), households could adopt a new technology, such as an improved stove, if the perceived benefits of adoption are greater than the costs. A study (Parikh, 2000) on the impact of rural energy on the health impacts of poor rural communities in the three Indian states of Rajasthan, Himachal Pradesh and Utter Pradesh finds that the cost to poor families due to days lost collecting fuelwood, lost earnings and cost of medical treatment of adults is 85 billion rupees ($1.84bn) per year. Days lost due to illness and due to time spent on collecting fuel came to 1 billion days for a population of 226 million.

3. Study Area and Data

Our study area consisted of five Village Development Committees in Rasuwa: Galtlang, Goljung, Chilime, Haku and Dhunche. The Rasuwa district lies in the northern part of Central Nepal, about 80 miles from Kathmandu. In 2001, there were 8696 households with a population of 44731 in the district (CBS, 2002). The main ethnic group (about 84%) of the area are Tamang. Most of the households (91.3%) in the area are totally dependent on biomass energy for cooking and room heating. Among this number, most households undertake cooking activity on inefficient traditional stoves in poorly ventilated kitchens. However, some households have installed smokehoods and undertaken changes in the traditional stove in order to mitigate the problem of indoor air pollution with the financial and technical support of Practical Action Nepal.

Practical Action Nepal, an International Non-Governmental Organization (INGO), has been facilitating villagers in Rasuwa[3] to adopt appropriate technologies to alleviate indoor air pollution since 2001. It has facilitated village communities to select and develop efficient, appropriate and sustainable technological solutions to reduce the IAP problem in Rasuwa district. They used a participatory approach[4] to identify appropriate technology to solve the IAP problem. After experiments, the customers chose the smokehoods technology with stove modification. Under the Practical Action Nepal project in Rasuwa, the smokehood is the major intervention, which is built against the wall with an improved tripod stove beneath it constructed with a mud base. The protective base around the back and the two sides of the tripod stove are made with mud. Likewise, a bar is set across the front of the stove to allow air to pass beneath it to improve combustion. The smokehood sucks away the smoke produced during the incomplete combustion of fuelwood while cooking. The organization took into consideration the special needs of the high hill region where room heating is one of the prime requirements besides cooking while designing the smokehood. Moreover, by incorporating a grill rod inside the smokehood, they made provisions for smoking meat and agro-based products. Users preferred the technology because of its practicality and appropriateness as it reduces the level of pollution, radiates heat inside the room, and allows them to cook the way they want using different types and sizes of pots[5].

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[3] *The author works for the Practical Action Nepal Office.*

[4] *The participatory approach adopted by Practical Action Nepal includes working with communities, discussing with the households about the risks of indoor air pollution, and working with them to find solutions. By applying technical know-how to potential solutions identified by the community, they designed acceptable technology which proved to be effective.*

[5] *Details about the intervention can be found in Practical Action 's website (www.practicalaction.org).*

Five local entrepreneurs trained by Practical Action Nepal are actively involved in the supply and installation of the smokehoods. A smokehood costs about Rs. 5000. There are about 15 revolving fund groups supported by Practical Action Nepal. The local revolving fund groups provide loans to customers to buy smokehoods. The interested household becomes eligible for the loan from the revolving funds after paying the initial membership fee and a down-payment, which is 20 percent of the total product and installation cost. The customer pays back the loan within two years in monthly instalments. The entrepreneurs had been able to install approximately 450 smokehoods in Rasuwa up to July 2007.

This study is based on primary data collected from household surveys and indoor air quality monitoring. In 2006, we administered household surveys to 400 households (80 with and 320 without intervention). Under the household survey, we attempted to collect information on demographic characteristics, resources, skills, climate, household characteristics, energy use, income, health status, etc. We also assessed a range of factors that might influence pollution levels and exposures, known as confounding variables, during the course of the study so their potential effect could be accounted for in the analysis. We also collected information on kitchen size, ventilation, stove type, cooking practices and fuel type. We asked the main cook about adverse health symptoms mainly associated with indoor air pollution, such as, coughing, wheezing, phlegm, eye irritation, headaches, symptoms associated with COPD, etc., and about symptoms of respiratory illness in children. The questionnaire included questions on burns in order to establish whether the interventions were helping to reduce the levels of burns in small children. In addition, we also collected individual data from the household head on household members regarding their annual treatment cost for respiratory problems. First we calculated the treatment cost per incident for the survey year and added up the treatment cost for the particular household. The recall period for most variables was one year. But with respect to fuel use, it was just 24 hours (that is, for fuel use during smoke monitoring).

We conducted indoor air quality monitoring (CO and Particulates, two key emissions harmful to health) in the sample households. In 60 (30 user and 30 non-user) households we monitored PM_{10}[6] using Buck S.S. pumps, which is a low-flow sampling pump that draws in air, spins off the larger particles and deposits the lighter, more dangerous ones on a small circular disc of filter paper. We weigh the filter before and after monitoring; the difference in weight indicates the levels of the pollutants in the room. We calibrated the pumps prior to each 24-hour monitoring session using a Buck bubble calibrator.

To measure carbon monoxide, we utilized the Industrial Scientific ISC T82 real-time, single gas monitor. The machine gives real time monitoring results. Once monitoring takes place, we can download the data to a computer. We conducted the monitoring of CO in 203 households (123 without and 80 with intervention). In the survey kitchen, we set close together a particulate pump and a CO monitor, 1.3m vertically and 1.3m horizontally away from the stove. We conducted the monitoring for 24 hours.[7]

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6 *Fine particles measuring 10 micrometers or less, which are small enough to penetrate deep into the lungs and so potentially pose significant health risks. They can cause inflammation and worsen the condition of people with heart and lung diseases. In addition, they may carry surface-absorbed carcinogenic compounds into the lungs.*

7 *Details of smoke monitoring methods are available online at: http://www.hedon.info/goto.php/HouseholdSmokeMonitoring*

4. Methodology

We analysed the collected data to identify the linkages between IAP and health for the purpose of assessing the viability of investments in IAP mitigating technologies and programmes. In order to do this, the study establishes the link between the IAP level and technological interventions. We also estimate the marginal health costs associated with IAP and perform a Cost Benefit Analysis (CBA) of the intervention.

4.1 Determinants of IAP

Several studies (e.g., Brauer and Saxena, 2002; Freeman and de Tejada, 2002; Moschandreas *et al.*, 2002; World Bank, 2002; Dasgupta *et al.*, 2004) have identified the potential determinants of exposure to indoor air pollution: fuel type, time spent on cooking, structural characteristics of houses, cooking locations, and household ventilation practices (i.e., opening of windows and doors, etc.). WHO (2002) reports that indoor air quality may vary depending on the type of cooking devices, type of fuel, hours of burning fire, ventilation, location of kitchen and stove, user's behaviour (for example, fuel drying, use of pot lids, good maintenance and sound operation of the stove and food preparation style). From the literature and our understanding of the local situation, we identified the different factors which might have an effect on indoor air quality determination in rural Nepalese households. Those factors include stove and fuel type, housing structure, behavioural factors, family factors, weather factors and other sources of IAP like tobacco smoke, lighting, etc. With regard to fuel type, we considered the dryness of the solid biomass fuel in the analysis. Under housing structure, we considered the size of the kitchen and the number of windows. Behavioural factors include the stove use for room heating. Family factors include the number of family members, the use of the stove to prepare foods other than regular food and the number of hours of cooking. Weather factors include temperature and rain. We also took into consideration other sources of IAP such as tobacco smoking and lighting fuel. To find the determinants of IAP we estimate the following equation:

$$\begin{aligned} CO_i = {} & \beta_0 + \beta_1 \text{interven}_i + \beta_2 \text{rain\_d}_i + \beta_3 \text{avg\_temp}_i + \beta_4 \text{ k\_size}_i + \beta_5 \text{win\_n}_i + \beta_6 \text{family}_i \\ & + \beta_7 \text{ heat\_hrs}_i + \beta_8 \text{ ofood}_i + \beta_9 \text{ cook\_ses}_i + \beta_{10} \text{ light}_i + \beta_{11} \text{ smoking}_i + \varepsilon_{i1} \end{aligned} \tag{1}$$

where CO_i is a proxy measure of IAP in the i^{th} household's kitchen including PM_{10}. McCracken and Smith (1998) and Naeher *et al.* (2001) find a strong correlation between CO and PM_{10} indicating the usefulness of CO measurements as an inexpensive and accurate way of estimating PM_{10} concentrations. We choose the right hand side variables based on existing IAP literature while ε_{i1} is an error term. The main variable of interest is 'interven', which refers to the smokehood and stove improvement intervention. Other independent variables include rain dummy (rain_d), average temperature in the monitoring day (avg_temp), size of kitchen (k_size), number of windows (win_n), family size (family), use of stove for room heating (heat_hrs), preparation of food other than regular foods (ofood), number of cooking sessions (cook_ses), type of fuel for lighting (light) and tobacco use in kitchen (i.e., smoking). We define the variables presented above in Table 1. We estimate Equation (1) using Ordinary Least Squares method.

4.2 Valuation of Benefits

We consider four types of post-intervention economic benefits in this analysis: (i) health benefits leading to a reduction in treatment cost and savings in days lost due to ill health; (ii) fuel savings; iii) cooking time saving; and (iv) global environmental benefits due to greenhouse gas reduction. We consider the first three benefits mainly from the household perspective while we consider the environmental benefit also including other three benefits from a societal perspective".

We calculate the total health cost by adding treatment costs and the value of working days lost due to indoor air pollution. We consider only respiratory infections, mainly ALRI and upper respiratory infections (URI), for the analysis. There is strong evidence from previous epidemiological studies that air pollution contributes significantly to the occurrence of ALRI (WHO, 2007b) and URI (Mutius, 1995). Since the intervention had been available in the study area for only a short period of time, we were able to consider only the immediate acute health impacts while we had to ignore chronic diseases resulting from long term exposure.

The total treatment costs (TC) include the cost of treatment and diagnosis (hospital/doctor's fee), lab charge, dietary expenses, and transportation costs and food expenses of the patient and caretakers. Days lost (DL) refers to the cost associated with the loss of productivity and days of work lost due to illness. It is the sum of time loss of the patient and his/her attendants. During illness the patients need to travel for treatment, stay in hospital or rest at home while the attendants are responsible for giving proper care to the patient. To estimate the marginal effect of interventions on treatment costs and day loss, we used the following two equations:

β

$$TC_i = \beta_0 + \beta_1 \text{ interven}_i + \beta_2 \text{ smoking}_i + \beta_3 \text{ health\_dist}_i + \beta_4 \text{ road\_dist}_i + \beta_5 \text{ lincome}_i + \beta_6 \text{family}_i + \beta_7 \text{ below5}_i + \beta_8 \text{ above60}_i + \beta_9 \text{ chronic}_i + \varepsilon_{i2} \quad (2)$$

$$DL_i =_0 + \beta_1 \text{ interven}_i + \beta_2 \text{ smoking}_i + \beta_3 \text{ health\_dist}_i + \beta_4 \text{ road\_dist}_i + \beta_5 \text{ lincome}_i + {}_6\text{family}_i + \beta_7 \text{ below5}_i + \beta_8 \text{ above60}_i + \beta_9 \text{ chronic}_i + \varepsilon_{i3} \quad (3)$$

where TC_i (lcost_rs, log of total treatment cost) refers to the i^{th} household's treatment cost and DL_i (loss_day) refers to the days lost. The explanatory variables are intervention (intervene), smoking in the kitchen (smoking), distance to health facilities (health_dist), distance to road head (road_dist), log of income level (lincome), size of family (family), number of children below 5 years (below5), number of the old above 60 years (above60) and chronic illness (chronic) in the household. We further define these variables in Table 1. In our sample, the treatment cost is zero for several households. In view of the truncated nature of the dependent variable, we use the Tobit regression for estimation of the treatment cost. As the day loss (DL) is count data we use negative binomial regression for estimation.

In order to estimate the marginal firewood savings from kitchen interventions, we also estimate the following firewood consumption equation:

$$\text{fuel\_q}_i = {}_0 + \beta_1 \text{ interven}_i + \beta_2 \text{ ofood}_i + \beta_3 \text{ family}_i + \beta_4 \text{ lincome}_i + \beta_5 \text{ ofuel}_i + \beta_6 \text{ rain\_d}_i + \beta_7 \text{ heat\_tim}_i + \beta_8 \text{ cook\_ses}_i + \beta_9 \text{ fuel\_tim}_i + \varepsilon_{i4} \quad (4)$$

where fuel_q_i is the quantity of firewood used by the i^{th} household. The explanatory variables are intervention (intervene), type of prepared food (ofood), family size (family), log of income level (lincome), rain (rain_d), use of stove for heating purpose (heat_tim), number of cooking sessions (cook_ses) and fuel collection time (fuel_tim).[8]

We calculate the marginal saving in firewood due to the kitchen intervention from the above firewood consumption equation (4). We also have household data from the survey on hours spent per unit of fuelwood collected. With this information and the marginal fuelwood saved, we estimate the annul firewood collection time savings. We calculate the monetary value of time savings by multiplying the time saved in fuel collection by the wage rate (Rs.100/day).

Similarly, based on data from the household survey, we also calculate the time saved in average cooking time after the intervention. We use the mean difference in cooking time between households with and without the intervention as the time savings from the intervention. From this we derive the monetary value of time saved in cooking activity. The monetary value of cooking time saved is the total cooking time saved multiplied by the shadow wage rate.[9]

The intervention in the study area may have a small but positive impact on global climate change through the reduction in firewood consumption. The burning of solid fuels leads to the emission of many different greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (NO_2), etc. The CO_2 emission is the highest from fuelwood burning, which is also recognized under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Therefore, in this analysis we only consider CO_2 emission. We assume that each kilograms (kg) of non-renewably harvested firewood burned generate 1500g CO_2[10]. The monetary value of the global environmental benefit is the total CO_2 that is not released into the environment due to the firewood that is not used multiplied by the unit international market price of the carbon.

4.3 Cost Estimate

We calculate the initial capital investment for a household as the sum of the market price of the smokehood, the installation cost of the hood, and stove improvement costs. Similarly, we have also taken into consideration in this analysis the recurrent fuel costs, operation, repair, and maintenance costs. For the CBA analysis from a societal perspective, we have included the programme cost, i.e., the direct programme cost of Practical Action Nepal.

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8 *As the households collect firewood freely from nearby forests, we did not include the price of firewood in the demand function of firewood. Similarly, since the time to collect the firewood is the same for all households, we ignored it in the analysis.*

9 *We used the shadow wage for time saved in the economic analyses in order to calculate the true economic price, which was considered to be 50% of the going wage rate.*

10 *Habermehl (2007) assumes each kg of firewood burned generate 1500g CO_2. WHO (2006) global study has used one kg firewood use equivalent to 1688g CO_2 generation in average. There is no significant difference between the two figures (convertion rates), so in this study we use CO_2 covertion rate as used by Habermehl (2007).*

4.4 Benefit Cost Analysis

We have conducted the benefit cost analysis from two perspectives: (i) an economic analysis to assess the social benefit from a societal perspective, and (ii) a financial analysis to assess private benefits from a household perspective.

All the prices in the analyses are based on 2006 market prices. We applied a shadow wage for time saved in the economic analyses in order to calculate the true economic price. The shadow wage rate used is 50 percent of the going wage rate for women. We have based this on the assumption that women would use only 50 percent of their saved time on income generating activities, farming and home-care-related activities.[11]

We assume the life of the intervention to be 10 years and, therefore, calculate the annual benefit and cost cash flow for a 10 year period. From the net cash flow, we calculate the Benefit-Cost (B/C) ratio, Net Present Value (NPV) and Internal Rate of Return (IRR). We derive the B/C ratio and NPV using the standard discount rate of 12 percent in the financial analysis (analysis from a household perspective). Some of the benefits of investments to improve indoor air quality will be visible in the long run only. These interventions also have long term environmental benefits for future generations which will not be limited to a single household. Therefore, we applied a lower social discount rate of 3 percent in the economic analysis. In addition, in order to check the robustness of the results and the risk associated with the benefit and cost, we performed a sensitivity analysis. We checked the sensitivity of investment in case of cost increase, benefit decrease, or both.

$$NPV = \sum_{t=1}^{T} \frac{(B_t - C_t)}{(1+r)^t}$$

We calculate the NPV and B/C ratio (BCR) using the following equations:

$$BCR = \frac{\sum_{i=1}^{r} \frac{B_t}{(1+r)^t}}{\sum_{i=1}^{r} \frac{C_t}{(1+r)^t}} \qquad (5)$$

where r is the discount rate, t is the year, B_t is the benefit and C_t is the cost in time t and IRR is the rate for which NPV equals zero.

[11] *Habermehl (2007) also uses the same rate.*

5. Results and Discussions

5.1 Indoor Air Pollution Problem in Rural Nepal

All the households use firewood for cooking in the surveyed area. Only a few (1%) households use clean fuels (biogas, LPG, etc.) along with firewood. The average annual firewood consumption is 2,744 kg (see Table 1). Due to the high use of firewood (solid fuel), the pollution in the kitchen is very high. Table 2 shows that the twenty-four hour average PM_{10} level is 763 µg/m^3 in households without intervention (control group), which is about 15 times higher than the WHO recommended safe level of 50µg/m^3. In the sample households with intervention, the 24 hour average PM_{10} level is 255µg/m^3 which is 66% less than for the control group (see Table 2).

The WHO recommends an 8 hour average of CO which is not more than 9 ppm. Our findings indicate that the 24 hour average CO level is 9.39 ppm in households with traditional stoves compared to 2.26 ppm (that is, 76% less) in households with smokehoods. The results show that the difference in the levels of pollution (PM_{10} and CO) in the intervention and control groups is statistically significant (see Table 2). Our results suggest that there is a strong correlation ($r = 0.813$) between CO and PM_{10}. McCracken and Smith (1998) and Naeher *et al*. (2001) report similar results. Such high correlation indicates that CO measurements can be an inexpensive and approximate way of estimating PM_{10} concentrations. On the basis of this evidence, we use CO as a proxy measure of PM_{10} in our analysis.[12]

We assess a range of factors that might influence indoor air pollution levels, known as confounding variables, in order to analyse their potential effects on CO. We estimate Eq (1) using the ordinary least squares (OLS) method. We present the results in Table 3. Our results indicate that the coefficient of intervene (smokehoods and stove improvement) is negative and significant (-6.74) indicating that interventions are effective in reducing the indoor air pollution level significantly. More specifically, the average reduction of CO concentration due to intervention is 6.74 ppm. This result is consistent with what we observe in Table 2. Likewise, the size of the kitchen significantly reduces the IAP level: the larger the kitchen area the lower the IAP level. On the contrary, the use of the stove for purposes other than cooking regular food, such as making alcohol, preparing animal feed and for room heating has a significant positive effect on CO concentrations. We also find a positive and significant effect on IAP levels of the number of cooking sessions and smoking. Other variables such as use of polluting fuel for lighting, the family size, the number of windows in the kitchen have no significant effect on IAP levels.

5.2 Measurement of Economic Benefit from Intervention

The occurrence of respiratory illnesses (e.g., cough, phlegm, and wheezing symptoms) is significantly different among the cooks (Table 4) and children (Table 5) of the intervention and control groups. The probability of reduction in respiratory illness in women cooks and children below 5 years after the intervention is significantly high (see Table 6). The OLS result suggests that the intervention contributes to a reduction in treatment costs by about Rs. 603/year per household (see Table 7). The Government provides medical check-ups and medicines at

[12] *With the use of the filter and buck pump, the PM_{10} monitoring process was quite lengthy. Therefore, we were able to monitor it in 60 HHs only.*

subsidized rates in the area through public health facilities. On average the cost of subsidized medicines and health check-ups comes to approximately Rs.375/HH/year (see Table 2). If we factor in this cost, the marginal saving due to intervention would come to about Rs. 978/year per household. Likewise, there were savings in sick days after the intervention due to fewer occurrences of diseases. As Table 8 shows, the saving in annual sick days for people in the economically active age (patient and caretaker) is approximately 10 days/HH due to the intervention, which is equivalent to Rs. 1000/year (or Rs. 500/year in economic price[13]).

We also analyze the impact of the intervention on fuel consumption. Table 9 presents the regression result on the determinants of firewood consumption. It is clear that the intervention results in a significant decline in firewood consumption. In the case of OLS, the average firewood saving per day due to the intervention is 3.15 kg per household (roughly 1150 kg/year). The households in the study area do not purchase the fuelwood but collect it from nearby forests. In our sample, the amount of firewood collected per person per trip is approximately 30 kgs on average. The average time per trip comes to about 6.41 hrs. Our results indicate that approximately 31 workings days (the equivalent of Rs. 1550 in economic price) are saved per household annually with the installation of the improved stove with smokehood.

In addition, improved stove efficiency and changes in cooking practices lead to significant savings in cooking time. The analysis suggests that intervention saves 14 minutes/day (or approximately 84 hours/year, as seen in Table 2) of cooking time. If converted into monetary terms, this saving is equivalent to approximately Rs. 525/HH in economic price per year.

Finally, due to the significant reduction in the use of firewood at 1150kg/year, we estimate that there would be about 1,700kg/hh/year less of CO_2 emission which contributes to an improvement in the global environment. If we assume the economic value of one tonne of CO_2 avoided to be approximately US$6.00,[14] the saving in firewood use results in a saving of Rs.724/HH/year in terms of a reduction in the level of CO_2 emission.

5. 3 Endogeneity Issue

We have treated the intervention up to now as an exogenous variable. However, when selecting households for indoor smoke alleviating technology adoption, the project provided the technology to interested households. The project created a revolving fund to address the credit constraints of low income households and provided loans to interested customers, who then used the loans to buy the kitchen improvements. The adoption of the new technology, however, may depend on the degree of air pollution in the kitchen, the quantity of firewood needed for cooking and heating, and the health impacts of the polluted air coming from the kitchen. The potential dependency of technology adoption (*interven*) on the dependent variables (CO, TC, DL and fuel_q) in equations (1) through (4) creates an endogeneity problem.

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[13] *Economic price includes direct, indirect, and hidden costs like opportunity cost.For the time saving, we assume that only 50 percent of the saved time would be used productively so it is less than the financial price. The average daily wage rate in the study area is Rs.100/day.*

[14] *In this study, the exchange rate between the US$ and Nepalese currency was taken as US$ 1.00 = Rs.70.00.*

In order to address the possible endogeneity issue, we use an instrumental variable (IV) approach while estimating equations (1) through (4). The adoption of new technology may depend on the household income and the knowledge of the person making decisions on adoption about the link between indoor air pollution and health outcomes of family members. It is possible to take the education levels of household members as proxy knowledge about the effects of indoor air pollution on health. We, therefore, use household income and education level as instruments for intervention (*intervene).* We also use the sex-ratio as an additional instrument for intra-household decision making capacity when it comes to adopting the improved stove. The decision to adopt an intervention may depend on the bargaining power of the female who generally spends more time on cooking and therefore is more affected by the polluted air.

The contribution of intervention (*interven*) goes up in all cases when we correct for endogeneity. The results from IV estimates indicate that the effect of intervention on reduction in indoor air pollution is even stronger when we correct for endogeneity. The reduction in CO levels goes up from 6.74 ppm to 8.82 ppm if we compare the results from the OLS and IV methods. We also estimate an alternative model with an alternative set of instruments, where income is replaced by land holding. But the results are not sensitive to the alternative set of instruments.[15] For example, the reduction in treatment cost increases to Rs 987 from Rs 603 (see Table 7) while the marginal saving (which includes government subsidies) is Rs 1352. The saving in annual sick days also goes up to 19 days/HH/year (the equivalent of Rs 1900/year in financial terms and Rs 950/year in economic terms) in the case of IV estimates (see Table 8). The average firewood saving per day due to the intervention is 4.82 kg for each household (about 1527kg/year, see Table 9). This translates into a saving of 40 working days per year per household (the equivalent of around Rs. 2000 in economic price).

Our analysis indicates that there would be 1725 - 2290 kg/hh/year less CO_2 emission due to the reduction in firewood use (approximately, 1150 – 1527 kg/year) based on the OLS or IV estimation method. The reduction in firewood use results in savings of Rs.724 – Rs. 962/hh/year in terms of a reduced level of CO_2 emission.

5.4 Cost of Intervention

We calculate the intervention costs to the households as well as to society. The initial investment cost for the intervention per household is approximately Rs.5000/HH with a maintenance requirement of Rs.100/year (see Table 10). This cost is estimated as net costs based on the costs of smokehoods plus stove modification minus the cost of the traditional stove. Similarly, we calculated the programme cost based on Practical Action Nepal's direct programme cost in Rasuwa in order to calculate the cost to society. The total programme cost was approximately Rs. 4.76 million (1.12 million for seed money, 0.79 million for grants and 2.85 million for other programme costs) during the 3 years of the project period (see Table 10).

[15] *This particular set of results is not reported here but is available upon request.*

5.5 Cost Benefit Analysis

A household's decision to install a smokehood depends on the direct costs and benefits to the household. Hence, we carry out a cost benefit analysis to assess the viability of the investment for intervention. For a household, the total investment includes the price of intervention (smokehood installation and stove modification cost) which comes to about Rs. 5000 with a maintenance requirement of about Rs. 100/hh per year (see Table 10). The annual financial benefit of the intervention is Rs. 987/HH from treatment costs and Rs. 1900/HH (19 days) from health care related time savings. Similarly, there is a Rs. 5050/HH (or 50.5 days) saving from indirect time savings (i.e., time savings in cooking and firewood collection). Thus, the total annual financial savings come to about Rs. 7,937/HH/year (see Table 10). A benefit cost analysis from the household perspective suggests that the investment in a smokehood is highly viable on economic grounds with the estimated Financial Internal Rate of Return (FIRR) being 156 percent, which is about thirteen times higher than the cut-off discount rate (12%). If we consider only the health benefits of the intervention (ignoring other benefits), the IRR comes to about 55 percent. If we consider only the monetary cost saving (that is, the treatment cost saving in cash), the IRR comes down to 12 percent (see Table 11).

We perform a sensitivity analysis in order to check the robustness of the results and the risk associated with the underlying benefit and cost assumptions. The results of the sensitivity analysis show that the investment in smokehoods is viable even in the case of an increase in the product cost by 20 percent or a decrease in associated benefits by 20 percent. Even in the combined case, the BC ratio is greater than the unity, indicating the viability of the investment.

In order to check the viability of the indoor air pollution alleviation programme from a societal perspective, we undertake an economic cost benefit analysis. Because of increased awareness, a smooth flow with regard to supply, easily accessible after sales service and availability of loan facilities through revolving funds, we expect approximately 640 households to benefit from the intervention in the project area. The CBA analysis from a societal perspective shows that the investment in scaling up the programme on indoor smoke alleviating technologies is economically viable with an Economic Internal Rate of Return (EIRR) of 71 percent. Similarly, the analysis shows that over a 10 year period, the NPV will come to Rs. 20.1 million with a B/C ratio of 4.7 at the 3 percent discount rate (see Table 11). The results of the sensitivity analysis indicate that the investment in kitchen smoke alleviation programmes is viable even if programme costs increase by 20 percent or benefits decrease by 20 percent. Even if the project costs increase by 20 percent and the benefits decline by 20 percent, the BC ratio remains greater than the unity (2.2). Moreover, even in the absence of financial benefits from CO_2 savings, the programme seems viable with an IRR of 57 percent.

6. Conclusions and Recommendations

In rural Nepal, most of the households are totally dependent on solid biomass fuel for cooking energy. The biomass reliance has been contributing to external economic cost such as deforestation, green house gas emission, drudgery and ill health of rural women and children. The research findings of our study show that the indoor air pollution level is very high (15 times higher than the recommended safe level) in the study area where households use solid biomass fuel for cooking on traditional inefficient stoves. Indoor air pollution is one of the key factors of major health problems, mainly ALRI, and results in high expenditure in terms of treatment and loss of productivity. There is urgent need to increase the access to cleaner fuels and improved technologies to overcome these problems.

The smokehood with improved stove designs has proved to be very effective in reducing the indoor air pollution levels. The benefit-cost analysis suggests that it is viable to invest in this product and its scaling up programme. Yet, the adoption of these interventions is very limited. There are several reasons why scaling up is not taking place. The three most obvious ones are: i) the information gap – i.e., households not aware of the benefits; ii) expenditure incurred in the intervention and the lack of credit facilities; iii) the absence of a regular supply of intervention technologies because there is no established market. It is imperative for policy makers to deal with these challenges if the problem of indoor air pollution is to be seriously addressed.

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TABLES

Table 1: Household Characteristics - Descriptive Statistics

	Unit	Minimum	Maximum	Mean	Std. Deviation	N.
Total family size	Nos.	1	13	5.17	1.904	400
Intervention	Dummy	0	1	0.20	0.401	400
Income	Rs.'000/year	2.50	354.00	70.10	59.71	400
CO level – 24 hrs average	ppm)	0.24	74.69	6.58	7.97	203
PM_{10} – 24 hrs average	$\mu g/m^3$	79	2,755	509	482	60
Annual fuel consumption	Kg./Year	900	8,258	2,744	841	400
Annual time spent for firewood collection	Hours/Year	180.00	1,650.00	585.18	219.63	400
Use of dry fuel	Dummy	0	1	0.97	0.18	400
Total hours of cooking a day	Hours/day	0.50	7.25	3.28	1.07	400
Children's day loss due to illness	days/year	0.0	30.0	1.8	3.6	400
Days lost of economically active patients due to illness	Days/Year	0.0	97.0	8.4	9.7	400
Days lost of caretakers	Days/Year	0.0	97.0	4.9	8.4	400
Total household expenditure in treatment (cash)	Rs./Year	0	10,600	331	998	400
Frequency of illness	Frequency /Year	0.0	8.0	3.1	1.4	400
Total days lost of patient and caretakers excluding the children's day loss	Days/year	0.0	194.0	13.3	16.4	400
Subsidized medicines and check -ups received from health post	Rs.	0	1482	375	333.38	400
Rain	Dummy	0	1	0.35	0.478	400
Size of kitchen (m^3)	Meter	2.46	56.00	21.05	10.27	400
Number of windows in the kitchen	Nos.	0.00	3.00	1.30	0.97	400
Number of children below 5 years	Nos.	0.00	5.00	0.91	0.97	400
Number of adults above 60 years	Nos.	0.00	3.00	0.27	0.54	400
Number of cooking sessions	Events	1.00	6.00	3.57	0.85	400
Preparation of food other than regular	Dummy	0	1	0.04	0.196	400
Type of fuel for lighting (clean = 1, No = 0)	Dummy	0	1	0.37	0.483	400
Smoking	Dummy	0	1	0.43	0.495	400
Stove used for heating purpose	Hours	0.00	7.00	0.24	0.64	400
Chronic illness	Dummy	0	1	0.02	0.140	400
Distance from nearest health facilities	Hours/visit	0.03	2.50	0.55	0.76	400
Distance from motorable road head	Hours/visit	0.05	4.00	1.66	1.62	400
Sex ratio	Ratio	0	7	1.335	0.990	394
No. of family members having secondary level education or more	Number	0	1	0.295	0.457	400

Table 2: Characteristics of Intervention and Control Households

Description	Unit	Without intervention	With intervention	t-stat
Number of HHs	Nos.	320	80	
Total Family Size	Nos.	5.07	5.60	-2.256**
Percent of population (0 - 5 Years)	%	16.5%	21.2%	2.928***
Percent of population (6 - 15 Years)	%	24.1%	25.9%	-1.499
Percent of population (16 - 60 years)	%	55.6%	50.4%	-0.037
Percent of population (60 years over)	%	5.7%	3.1%	1.717*
Dependency ratio	%	27.85%	31.85%	
Land holding (ropani)	Ropani	9.51	12.16	-3.156***
Income (Rs./year)	64,630	91,995	-3.725**	
PM_{10} Level - 24 hrs average	(mg/m3)	764	255	4.78***
CO level - 24 hrs average	(ppm)	9.39	2.26	6.91***
Annual fuel consumption	(kg/year)	2,886	2,174	7.19***
Annual trip for fuel collection	(hours)	96	73	7.17***
Average fuel collection time per *bhari*	(minutes)	6.41	6.33	0.473
Annual fuel collection time (in hours)	Hours/year	617	454	6.23***
Daily cooking hours	Hours/day	3.32 (3 hours 19 minutes)	3.09 (3 hours 5 minutes)	1.70*
Carbon dioxide (CO2) emission	(kg/year/HH)	4329	3261	7.19***
Frequency of illness due to IAP	Episodes/year	3.3	2.5	4.35***
Days lost due to IAP generated health problems	-	-	-	-
Days lost of economically active population due to illness (days/year)	Days/year	9.55	3.84	4.82***
Days lost of children below 15 years	Days/year	2.00	0.74	2.39***
Days lost to caretakers	Days/year	5.63	1.94	3.53***

**** Significant at 1% level, ** significant at 5% level and * significant at 10% level*
Note: The number in the parentheses is the standard deviation of the variable
Source: Household Survey, 2006

Table 3: OLS and IV Regression Results (Dep. Var.: CO level)

	OLS		IV Estimates	
Variables	Coefficient	t-stat	Coefficient	t-stat
Intervention -6.74	-5.35***	-8.82	-2.24**	
Rain Dummy-0.65	-0.51	0.17	0.12	
Average Temperature	0.32	2.14**	0.20	0.91
Size of kitchen	-0.11	-2.20**	-0.12	-1.82*
Number of windows in the kitchen	0.26	0.50	0.26	0.47
Total family size	0.26	1.02	0.35	1.16
Hours used for heating purposes	1.93	2.78***	2.11	2.83***
Foods other than regular food prepared	4.88	2.23**	4.65	1.97*
Number of cooking sessions	1.34	2.44**	1.57	2.67***
Use of polluting fuel for lighting	0.04	0.03	-0.49	-0.38
Smoking Dummy	3.32	3.41***	2.96	2.83***
(Constant)	-3.25	-0.82	-2.57	-0.43
R Square	0.337		0.257	
Adjusted R Square	0.299		0.213	
Number of observations	203		203	
F-value	8.083***		5.84***	

Table 4: Symptoms of Illness in Main Cook (Woman) over 12 months Period

Symptoms	Without intervention		With intervention		Difference	t- stat
	%	SD	%	SD		
Cough						
Cough first thing in the morning or at other times of the day	93.4%	0.25	67.5%	0.47	25.9%	6.790***
Cough for more than 3 months	48.1%	0.50	18.8%	0.39	29.4%	4.886***
Cough at least 3 months for 2 or more years	45.0%	0.50	17.5%	0.38	27.5%	4.607***
Cough most days, at least 3 months, for 2 more years	24.1%	0.43	15.0%	0.36	9.1%	1.745*
Phlegm						
Had phlegm during last 12 months	89.1%	0.31	65.0%	0.48	24.1%	5.466***
Usually phlegm on most days?	86.3%	0.34	65.0%	0.48	21.3%	4.526***
Phlegm for at least 3 months last year	47.5%	0.50	16.3%	0.37	31.3%	5.237***
Phlegm at least 3 months, for more than 2 years	43.8%	0.50	15.0%	0.36	28.8%	4.865***
Phlegm most days, at least 3 months, for more than 2 years	41.6%	0.49	15.0%	0.36	26.6%	4.521***
Episodes of cough and phlegm						
Episodes of both cough and phlegm continue for 3 weeks	60.9%	0.49	12.5%	0.33	48.4%	8.389***
Cough and phlegm for more than 2 years	40.6%	0.49	1.3%	0.11	39.4%	7.108***
Wheezing	20.3%	0.40	7.5%	0.27	12.8%	2.700***
Sore/watering eyes most of the days	28.8%	0.45	5.0%	0.36	23.8%	4.552***
Headaches for most of the days	30.0%	0.46	7.5%	0.27	22.5%	4.210***
Smokers	66.0%	0.474	65.0%	0.480	1.0%	0.211

Note:
Total sample for without intervention was 320 compared to 80 with intervention case
**** significant at 1% level; ** significant at 5% level; * significant at 10% level*
Source: Household Survey, 2006

Table 5: Symptoms of Illness in Children below 5 Years over last 12 months Period

Illness Symptoms	Without		With		Difference	t- stat
	Mean	SD	Mean	SD		
Cough during last two weeks	81.0%	0.39	20.4%	0.41	60.7%	9.663***
Breathe rapidly during coughing	75.8%	0.43	16.7%	0.38	59.2%	8.973***
Coughs and Colds of Children over last 12 months period	86.9%	0.34	64.8%	0.48	22.1%	3.670***
Burn or scalds over last 12 months period	5.2%	0.25	0.0%	0.00	5.2%	1.528
Pneumonia over last 12 months period	6.5%	0.25	5.6%	0.23	1.0%	0.254
Average number of children below 5 years	0.69	0.84	1.04	0.82		3.24***

Note:
153 non-user and 53 user households reported they had children below 5 years.
**** significant at 1% level; ** significant at 5% level; * significant at 10% level*
Source: Household Survey, 2006

Table 6: Probability of Reduction in Illness in Women Cooks and Children below 5 years after Intervention

Symptoms	Probability of reduction in illness after intervention (marginal effect)	z-statistics
Symptoms in Women Cooks		
- Chronic cough	-0.279	-4.31***
- Chronic phlegm (phlegm for more than 3 months)	-0.302	-4.66***
- Cough and phlegm symptom regularly for 3 weeks	-0.503	-7.24***
- Wheezing	-0.104	-2.14**
- Sore/Watering Eyes	-0.237	-4.16***
Symptoms in Children below 5 years		
- Cough	-0.607	-7.55***
- Breathing rapidly during coughing	-0.592	-7.20***

Note: (i) The results were derived from separate Probit Regression Analyses
*(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level;*

Table 7: OLS, IV and Tobit Results (Dep. Var.: log of treatment cost)

	OLS		IV- Estimates		Tobit regression	
	Coef.	t-stat	Coef.	t-stat	Coef.	t
Intervention	-1.824	-5.61***	-2.986	-2.37**	-2.160	-5.57***
Smoking by a household member (Dummy)	-0.003	-0.01	-0.014	-0.05	-0.085	-0.28
Distance from health facilities (in hours)	0.822	4.74***	0.999	3.87***	0.848	4.14***
Distance from motorable road head (in hours)	0.136	1.69*	0.156	1.79*	0.129	1.36
Total family size	-0.004	-0.06	-0.014	-0.19	-0.005	-0.07
Log of income (Rs. '000/year)	0.834	4.68***	1.000	3.95***	0.944	4.50***
Number of children below 5 years	0.128	0.94	0.213	1.35	0.199	1.25
Number of adults above 60 years	-0.426	-1.92*	-0.521	-2.05**	-0.431	-1.66*
Chronic illness (Dummy)	2.367	2.72***	2.771	2.82***	2.757	2.73***
(Constant)	-0.314	-0.42	-0.877	-0.89	-0.960	-1.08
R square	0.1422		0.0856	Log likelihood	-874.114	
Adjusted R square	0.1224		0.0641	Sigma	2.708849	
F	7.18***		3.99***	Pseudo R2	0.0302	
Number of observations	400		400	Number of observation	400	

*Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level*

Table 8: Marginal Effects: Negative Binomial Estimates (Dep. Var.: Days lost due to Illness)

	Regression		IV Estimates	
	dy/dx	z	dy/dx	z
Intervention -10.491	-9.86***	-19.157	-2.86***	
Smoking by a household member (Dummy)	0.314	0.24	0.696	0.46
Distance from health facilities (in hours)	1.707	1.95*	2.873	2.14**
Distance from motorable road head (in hours)	-0.440	-1.07	-0.281	-0.57
Total family size	-0.217	-0.58	-0.448	-1.05
Log of income (Rs. '000/year)	2.399	2.63***	3.341	2.50**
Number of children below 5 years	0.767	1.12	1.216	1.42
Number of adults above 60 years	-0.539	-0.51	-1.486	-1.13
Chronic illness (Dummy)	7.045	1.04	13.371	1.25
(Constant) -10.491	-9.86	-19.157	-2.86	
Log likelihood	-1418.6568		-1424.5889	
lnalpha	-0.1492762		-0.0088178	
alpha	0.8613312		0.991221	
Pseudo R2	0.0215		0.0045	
Number of observations	400		394	

*Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level*

Table 9: Determinants of Firewood Consumption – OLS and IV Estimates

	OLS		IV Estimates	
	Coeff.	OLS	Coeff.	OLS
Intervention	-3.148	-10.39***	-4.815	-3.82***
Food other than regular food prepared (Dummy)	6.808	11.92***	6.497	9.69***
Total family size	0.511	8.47***	0.540	7.63***
Income (Rs. '000/year)	-0.103	-0.66	0.058	0.27
Use of other fuel (Dummy)	-2.325	-2.06**	-1.657	-1.24
Rain (Dummy)	-0.285	-1.16	-0.694	-1.65*
Stove used for heating purpose (Dummy)	-0.023	-0.13	0.142	0.62
Number of cooking sessions	1.743	13.25***	1.776	11.99***
Fuel collection time	0.049	0.58	0.005	0.05
(Constant)	-0.768	-0.81	-0.954	-0.89
R square	0.6045		0.5162	
Adjusted R square	0.5954		0.5048	
F	66.24***		45.52***	
Number of observations	400		394	

a Dependent Variable: Total use of fuel a day (in kg.)
*Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level*
Source: Household Survey, 2006

Table 10: Summary of Cost and Benefits (in Rs.)

Headings	Perspectives	
	House hold (in Rs.)	Societal (in Rs.)
Costs		
Cost of a smokehood	5000	(5000 + 150) x 640
Annual maintenance cost	100	100 x 640
Programme cost (excluding support for smokehoods)	-	2,850,870
Benefits		
- Treatment cost saving	987	(987+375) x 640
- Day loss due to illness saving	1900 (19 days)	950 x 640
- Annual fuel collection time saving (Rs/Year)	4000 (40 days)	2000 x 640
- Annual cooking hour saving (Rs/Year)	1050 (10.5 days)	525 x 640
- Carbon dioxide (CO_2) emission saving (Rs./Year)	-	962 x 640

Table 11: CBA Analysis – the Results

	PRESENT VALUE (NRs)		NPV @ 12% Discount rate(Rs.)	IRR	B/C Ratio
	Cost	Benefit			
Scenarios					
From Household Perspective					
With treatment cost (cash) saving only	5565	5577	12	12.06%	1.00
With health benefits only	5565	16312	10747	55.05%	2.93
Base Results (with total benefits)	5,565	44,846	39,281	156.73%	8.06
Sensitivity Results					
Total Project cost increase by 20%	6,678	44,846	38,168	130.25%	6.72
Total Project benefits decrease by 20%	5,565	35,877	30,312	124.95%	6.45
Total cost increase & benefits decrease by 20 % each	6,678	32,713	26,035	94.37%	4.90
From Societal Perspective					
Base Results	5,446,465	25,619,447	20,172,982	71.39%	4.70
Sensitivity Results					
Total Project cost increase by 20%	6,535,758	28,270,192	21,734,434	64.59%	4.33
Total Project benefits decrease by 20%	5,446,465	22,616,153	17,169,688	61.51%	4.15
Total cost increase & benefit decrease by 20 % each	6,535,758	22,616,153	16,080,395	49.32%	3.46
Without CO2 saving benefits	5,446,465	21,369,420	15,922,955	57.46%	3.92

ANNEXES

Annex : Survey Instruments

Instrument I: House, Household and Monitoring Datasheet

PART A: QUESTIONS TO BE ASKED BEFORE STARTING THE AIR MONITORING

H.1 Identifying household and cook		
1.1 Household number		H11
1.2 Date of interview	____day____mth____yr	H12
1.3 Time of day	Time =	H13
1.4 Morning or evening?		H14
1.5 Name of interviewer		H15
1.6 Identifier for interviewee (NOT her name)		H16
H.2. The family		
2.1 Age of interviewee:		*H21*

2.2 Demographic characteristics, literacy, education and occupation

Identification Code	Name of Household Member	Sex	Age	Marital Status	Education Status	For Children 6-14 yrs		Is member at home		Occupation Agriculture = 1 Animal husbandry = 2 Business = 3 Industry = 4 Services = 5 Study = 6 Occupational caste = 7 Wage labour = 8 Household chores=9 Others = 10	
						Is child currently studying Yes=1, No=2	If not studying - reasons	Yes=1 No=2	If no, reason for being away Work=1 Studying=2 Other=3		
		Male = 1 Female = 2	Completed years	Married = 1 Divorced = 2 Separated = 3 Widowed = 4 Unmarried = 5	Illiterate = 99 Can read & write but no formal edu= 98Completed years of schooling in years		Never studied=1 Need to work at home=2 Cannot afford =3			Primary	Secondary
Code	H2201	H2202	H2203	H2204	H2205	H2206	H2207	H2208	H2209	H2210	H2211
1											
2											
3											
4											

2.11 If you have school-age children, where do they usually do their homework? 1. In the kitchen 2. In another part of the house 3. Outdoors 4. Another house or building /5. No specific place or homework not done		H23
H.3. Types & uses of household fuel		
3.1 Using the fuel list below, what types of fuel do you use for the following purposes? (List in order of importance using numbers shown below)		

Wood =1 Dung = 2 Agricultural residues = 3 Other residues = 4	Charcoal = 5 Kerosene (Paraffin) = 6 Bottled gas (LPG) = 7 Solar cooker = 8 Solar electric (solar PV) = 9	Grid electricity = 10 Batteries = 11 Wax candle = 12 Other = 13

If 'other' fuel used, please specify fuel	Other fuel =

	Most important fuel	Second most important fuel	Third most important fuel	
3.1.1 Cooking (including drinks)	H3111	H3112	H3113	
3.1.2 Lighting	H3121	H3122	H3123	
3.1.3 Keeping warm	H3131	H3132	H3133	
3.1.4 Heating water for other purposes	H3141	H3142	H3143	
3.1.5 Beer brewing	H3151	H3152	H3153	
3.1.6 Cooking food/Making drink for selling (excluding beer)	H3161	H3162	H3163	
3.1.7 Cooking animal feed	H3171	H3172	H3173	
3.1.8 Electrical equipment	H3181	H3182	H3183	
3.1.9 Other task 1 (specify below)	H3191	H3192	H3193	
3.2 If fuel is used for another type of household task, please specify task (s)	3.2.1 Other task 1 = 3.2.2 Other task 2 =			H321 H322

H.4. Getting fuel; buying and gathering		
4.1 Is your main fuel gathered or bought? 1- all gathered 3- mostly bought 2- mostly gathered 4- all bought		H41
4.2 If you buy it, how much do you pay for it per week? (please remember to put in the unit of currency)		
4.2.1 Wood		H421
4.2.2 Charcoal		H422
4.2.3 Kerosene (paraffin)		H423
4.2.4 Bottled gas		H424
4.2.5 Grid electricity		H425
4.2.6 Batteries		H426
4.2.7 Wax candles		H427
4.2.8 Other (e.g. gelfuel)		H428
4.2.9 Total cost *(add up the costs above)*		H429
4.3 What are the reasons for buying fuel? (more than one reason can be selected) 1. Scarcity of fuel for gathering 2. Faster than gathering it 3. Cleaner for cooking 4. Other reason (please specify)		H43
4.3.1 If answer to last question was '4', what is your reason for buying fuel?		H431
4.4 If you or your family gather fuel, how often is it gathered? 1- every day 2- every second day 3- once or twice per week 4- less often		H44

4.5 If you or your family gather it, about how long, on average, does each collection trip take (hours and minutes) at this time of year?							
Season	Place of fuel collection	Collection time (Round trip)	How many *bharis* collected this season?	Who mostly does it?	Availability	Problems when gathering it (yes or no - if yes what)	Weight of a *bhari* in kg.
4.5.1 Winter (December-February)	H4511	H4512	H4513	H4514	H4515	H4516	H4517
4.5.2 Summer (March -May)	H4521	H4522	H4523	H4524	H4525	H4526	H4527
4.5.3 Monsoon (June -Aug)	H4531	H4532	H4533	H4534	H4535	H4536	H4537
4.5.4 Autumn (Sept. -Nov)	H4541	H4542	H4543	H4544	H4545	H4546	H4547

5. Fuel drying		
5.1 Do you ever use 'green' fuel (i.e., wood or plants that is still growing, or have been growing very recently, when collected)		
1. not applicable - household does not use biofuel 2. never 3. occasionally 4. usually 5. always		H51
5.2 The main fuel that you use – about how dry is it usually?		
1. not applicable – household does not use biofuel 2. Very dry 3. Dry 4. Damp 5. Wet 6. 'Green'		H52
5.3 Do you dry your main fuel before use?		
1. not applicable (not biofuel or always very dry) 2. never 3. occasionally 4. usually 5. always		H53
5.4 If you need to dry fuel, where do you dry it?		
1. Not applicable 2. Outdoors 3. Indoors over or close to the fire 4. Combination of outdoors and indoors 5. Indoors, away from the fire		H54
6. Effort for Indoor Smoke Alleviation		
6.1 To alleviate indoor smoke, have you undertaken any measures in the kitchen? 1 – Yes 2 - No		H61
6.2 If yes, what are they 1 – Using improved stove (metal) 2 – Using improved stove (mud-mortar) 3 – Using smokehoods 4 – Improved kitchen ventilation system 5 – Changed the fuel from dirty to clean fuel (using LPG, electricity, etc.) 6– Using dry fuel only		H62
6.3 How much expense did you go into to make the improvement in kitchen		H63
6.3.1. Market cost of the item		H631

6.3.2. Transportation cost (include wage rate of yours also if you have done the portering work)			H632
6.3.3. Installation cost (include wage rate of yours also if you have done installation work)			633
6.3.4. Annual operating and maintenance cost (include wage rate of yours also if you are involved)			H634
K. THE KITCHEN			
K.1. Kitchen type			
1.1 Is the kitchen: 1. Enclosed or 2. Semi-open?			K11
1.2 Is the kitchen: 1. – In separate building? 2- Separate room attached to rest of main house? 3. Part of main living area in house?			K12
K.2. Roof			
2.1 Type of roof in the kitchen: 1- Mud 4- Thatch 2- Ferro-cement 5. Tiles 3- Wooden Tiles 6. Other			K21
2.2 If 'other' please specify (This box should only be used if answer '6' has been given for the previous question)			K22
2.3 Permanent ventilation *in roof* of kitchen 1- None 2- Small holes (less than 10cm in diameter) 3- Large holes (more than 10cm in diameter) 4- No roof, or very open roof			K23
K.3. Walls			
3.1 Type of walls in room with stove 1. Mud or mud blocks 2. Soil/cement blocks 3. Wattle (woven sticks / reeds / bamboo) 4. Iron sheets 5. Bricks 6. Stone 7. Other	3.1.1 Main type of material used for walls		K311
	3.1.2 Second type of material for wall *(if necessary)*		K312
3.2 If 'other' wall material, please give details – this should be answered if the last question had an answer '7' for either main or second type of wall material			K313
K.4. Eaves spaces (i.e., spaces between the walls and the roof) in room with stove			
4.1 Depth of eaves spaces (*see manual*) 1- none 2. less than 10cm in depth 3. 10 – 30cm in depth 4. greater than 30cm in depth			K41
4.2 Length of eaves spaces 1. All round room 2. Along outside walls 3. Along walls within house 4. Other (*please indicate on sketch at end of questionnaire)*			K42
4.3 What shape is the eaves space (Type A; Type B; or Type C – *see manual*)			K43
K.5. Windows & doors			
5.1 How many windows are in the room where cooking is done? 5.2 What size are the windows in the room with the main stove? (Measure width and enter sizes in table below)			K51

Window Sizes Size 1 = 2 – 5cm Size 2 = 6 – 14cm Size 3 = 15 – 29cm Size 4 = 30 – 59cm Size 5 = >60cm	Window size Window 1 Window 2 Window 3 Window 4 Window 5		 K521 K522 K523 K524 K525
5.3 How many doors are there in the kitchen?		K53	
5.4 Is the door (s) usually open or closed?		K54	
K.6. The stove			
6.1 Record main type of stove below and secondary stove if used			
Type of stove 1. Three-stone or two-stone fire 2. Shielded mud fire or mud stove (including chimney stove) 3. Wood-burning ceramic stove (made of fired clay) 4. Metal stove/5. Improved charcoal stove 6. Pressurised kerosene stove 7. Non-pressurised kerosene stove	Main type of stove		K611
8. Gas stove 9. Solar cooker 10. Grid-powered electric stove 11. Other type of stove	Secondary stove *(if used occasionally)*		K612
6.2 If ‘other’ type of stove, please describe			K62
6.3 How many adults usually sleep in the room with the main stove?			K63
6.4 How many children usually sleep in the room with the main stove?			K64
6.5 Is this stove usually kept alight at night?			K65
6.6 Is a stove used in any other room in the house other than the kitchen? (Y / N)			K66
6.6.1 If ‘yes,’ do people sleep in that room? (please list who sleeps there)			K661
K.7 Smoke extraction			
7.1 Is there any type of smoke extraction in the kitchen (chimney stove, hood, etc.)?Yes/No			K71
7.2 If the answer is ‘yes,’ insert number by each type of smoke extraction method used to describe condition of hood or chimney (e.g. a smokehood in poor condition would have a ‘1’ put in the box beside ‘smokehood’)			
1=Poor condition 2= Fairly good condition 3= Very good condition	Extraction method 7.2.1 Chimney stove 7.2.2 Smokehood 7.2.3 Other: 7.2.4 If ‘other’ smoke extraction method is used, please describe (or sketch) it		 K721 K722 K723 K724
K.8. House layout *8.1 Referring to manual:* Please circle correct shape code to describe the shape of the house	A B C D		K81
8.2 Referring to the handbook, in order to determine the volume of the kitchen at a later date, please measure dimensions in metres:	(a) =		K821
	(b) =		K822
	(c) =		K823
	(d) =		K824

PART B: QUESTIONS TO BE ASKED AFTER THE AIR MONITORING
ALL THESE QUESTIONS REFER TO WHAT HAS HAPPENED DURING THE TIME THAT THE MONITORS WERE MEASURING THE SMOKE SO THAT WE CAN RELATE THE AMOUNT OF SMOKE TO WHAT HAS CAUSED IT
During the time that the monitor was working, we would like to know the way fuel was used
S.1 Cooking Sessions:
Times when cooking started - What time did each session begin since monitor switched on? Please write "No Cooking" in each box where cooking did not take place (for example, if there were only two lots of cooking done, please mark the remaining three with 'No Cooking' in each box)

Cooking sessions	What was cooked?	Starting time of cooking	How long did it take?	How many persons did you cook for?	What fuel did you use?	How dry were they?
1.1 First session	S111	S112	S113	S114	S115	S116
1.2 Second session	S121	S122	S123	S124	S125	S126
1.3 Third session	S131	S132	S133	S134	S135	S136
1.4 Fourth session	S141	S142	S143	S144	S145	S146
1.5 Fifth session	S151	S152	S153	S154	S155	S156
1.6 Sixth session	S161	S162	S163	S164	S165	S166

Fuel type (Code)		
No cooking =1	Other residues = 5	Solar cooker = 9
Wood =2	Charcoal = 6	Solar (PV) electric = 10
Dung = 3	Kerosene = 7	Grid electricity = 11
Agri - residues = 4	Bottled gas (LPG) =8	Other = 12
Dryness of fuel (Code)		
Not used = 1;	Dry = 3	Wet = 5
Very dry = 2	Damp = 4	'Green' = 6

S.2 Other uses of Stove		
2.1 Was the stove kept alight especially for heating (not cooking)? Yes /No		S21
2.2 If 'yes,' how many hours was fuel put onto the stove especially to keep it alight for heating?		S22
2.3 Was the stove kept alight especially for lighting (not cooking)? Yes /No		S23
2.4 If 'yes,' how many hours was fuel put onto the stove especially to keep it alight for lighting?		S24

I.1: Income from different sources: please state what is the range of your household's annual income.

Sources	Annual income (in Rs.)
4.2.1 Sale of agriculture products	
4.2.2 Sale of livestock products	
4.2.3 Sale of fruits	
4.2.4 From services	
a. Salary, pension, etc.	
b. Daily wages	
c. Received remittances from abroad sent by a family member	
d. Business	
e. Enterprise	
4.2.5 Others	
Total annual income	

Instrument II: Health questionnaire			
PART A: Questionnaire for Adult Members (Mainly for Cooks)			
ID. Identifying household			
ID1 Household number			
ID2 Name of interviewer			
ID3 Identifier for interviewee (NOT his/her name)			
ID4 Date of interview			
ID5 Age of interviewee			
ID6 Height of interviewee			
A. Cough			
A1 Over the last 12 months, have you usually had a cough first thing in the morning, or at other times of the day?		No (go to B1) Yes	1 2
A2 Do you usually cough like this on most days?		Yes No	1 2
A3 For how many months, in total, in the last year have you coughed like this?			
	9 or more months		1
	5 - 8 months		2
	3 - 4 months		3
	1 – 2 months		4
	less than 1 month		5
A4 For how many years have you coughed like this?		Years:	
B. Phlegm			
B1 Over the last 12 months, have you usually brought up phlegm from your chest (deep down in your lungs) first thing in the morning, or at other times of the day?	No (go to C1) Yes		1 2
B2 Do you usually bring up phlegm like this on most days?	No		1
B3 What colour is the phlegm <u>usually</u>?	Yes Clear or white Yellow or green Brown or black Red (streaked)		2 1 2 3 4
B4 For how many months, in total, in the last year have you brought up phlegm like this?			
	9 or more months		1
	5 - 8 months		2
	3 - 4 months		3
	1 – 2 months		4
	less than 1 month		5
B5 For how many years have you brought up phlegm like this?		Years:	
C. Episodes of cough and phlegm			
C1 Over the last 12months, have you had episodes of both (increased*) cough <u>and</u> phlegm together lasting for 3 weeks or more?**Increased if already have cough and/or phlegm*	No (go to section WH1)Yes		1 2
C2 How many such episodes did you have in the last year?	Number:		
C3 For how many years have you had at least one episode per year like this?		Years:	
WH: Wheezing			
WH1 Over the last 12 months, has your chest (your lungs) sounded wheezy or whistling?	No (go to H1) Yes		1 2
WH2 Has this happened when you have a cold?	No Yes		1 2
WH3 Has this happened at other times when you do not have a cold?	No Yes		1 2
WH4 For how many years has this wheeze been present (whether or not when you have a cold)?	(Put '1' if less than one year)	Years:	

SE. Sore eyes		
SE1 Over the last 12 months, have you tended to get sore, eyes? watering eyes?	No (go to J1) Yes	1 2
SE2 How often do you have sore/watering eyes?	Every day Most days Few days/week Once per week Less often	1 2 3 4 5
SE3 When do you get sore, watering eyes?	During use of the fire only All or most of the day At other times (specify)	1 2 3
SE4 What colour is the fluid, usually?	None Clear/watery Yellow/sticky	1 2 3
SE5 What do you think usually causes these sore, watering	Smoke Weakness of sight Other (specify)	1 2 3

TB: Questions to identify TB/possible TB		
TB1 Do you have night sweats?	No	1
	Yes	2
TB2 Have you noticed significant weight loss over the last 6 months	No Yes	1 2
TB3 Have you coughed up blood/red phlegm in the last year?	No Yes	1 2
TB4 (a) Have you ever been told by a doctor or health worker that you had TB?	No (Go to TB5) Yes Not sure	1 2 3
(b) If yes, or not sure, how long ago was this?	Years:	
TB5 Are you currently taking any medication for TB?	No	1
	Yes	2
	Not sure	3

H. Headaches		
H1 Over the last 12 months, have you tended to get headaches?	No (go to D1) Yes	1 2
H2 How often do you have headaches?	Every day Most days A few days per week Once per week Less often	1 2 3 4 5
H3 How strong are the headaches usually?	Very strong Fairly strong Mild	1 2 3
H4 What do you think usually causes these headaches?	Smoke Having a cold Weakness of sight Other	1 2 3 4
H5 If 'other' please specify		

PART B: Respiratory health of under-five children as rated by mother				
Respiratory health problems to include all upper (coughs, colds, etc) and more severe respiratory problems including coughs going into chest, with fever, etc.				
D1	How many children under five years of age do you have? If none, insert '0' and go to TM1)		Number of children under 5	
D2	Have any of your under-five children had an illness with a cough at any time in the last two weeks?		No (go to D6) Yes	1 2
D3	If yes, did they breathe in a noticeably more rapid way than usual with short, rapid breaths? *(if more than one child with cough, discuss youngest)*		No Yes	1 2
D4 D5	How old is the child with the cough? *(if more than one child with cough, discuss youngest)*		Years Months	
D6	What (other) respiratory health problems, if any, have your under-five children experienced in the last year? Do not promt !	None (go to D8)		1
		Coughs and colds		2
		More serious illness with difficulty breathing		3
		Other (specify)		4
D7	If 'other,' please describe			
D8	How many times have your under-five children been burnt or scalded in the last year? (if none, insert '0' and go to next section)		Number of times:	
D9	What was the age of the child at the time?		Years	
D10	If more than one child – discuss youngest		Months	
D11	For the most severe occasion during the last year, how severe was the burn?		No scar (go to next section) Small scar (<2 Rs coin) Large scar (>2 Rs coin)	1 2 3
D12	Where did this burn or scald occur?		Your kitchen Not in your kitchen	1 2
D13	How did this burn or scalding occur? Do not prompt!		Fell into fire Touched hot object Scalded when pot fell over Clothes caught fire Other (describe)	1 2 3 4 5
D14	If 'other' please describe –			
D15	What concerns, if any, do you have about burns and scalding to your children at the present time? – *continue over page if needed*			
D16	Is there anything else you would you like to say about the health of your children under 5 at the present time? – *continue over page if needed*			

TM 1: Could you provide information on family members who suffered from health problem from indoor smoke?

Name	Age	Symptoms	Where did you receive advice for treatment? 1 Health post or centre 2 Hospital 3 Private health practitioner 4 Local healer 5 Treatment at home 6 Did nothing 7 Other specify)	How much did you pay for advice Rs.	How much did you pay for treatment and medicine? Rs.	How much did you pay for the transportation?	Other expenses during treatment? (Lodging, food, diet, etc.)	Patient Days lost in the treatment (working, schooling, etc.)	Why did you not seek medical advice? 1 No money 2 no medical facility close by 3 No medicines/ doctors in health facility 4 No one to take 5 Others	Days lost to care takers? Nos.
TM101	TM102	TM103	TM104	TM105	TM106	TM107	TM108	TM109	TM110	TM111

Note: Use the codes given below for IAP related infections/diseases

Symptoms	Lower Acute Respiratory Infection	Others
Upper Acute Respiratory Illness	8 Persistent cough	14 Eye problem
1 Sore throat 2 Running/ blocked nose/sinusitis 3 Ear infection (ear aches) 4 Sudden high fever 5 Cough while lying down 6 Headache 7 irritability and fatigue	9 Pneumonia 10 Chest congestion 11 Wheezing in chest 12 Chest pain while breathing 13 Asthma	15 Burn 16 Other

IN. Inhaling pollutant			
IN1	Do you smoke, or have you ever smoked, cigarettes? Answer 1: Go to IN8 Answers 2 & 3: Go to IN7	Never Gave up more than year ago Gave up during last year Yes	1 2 3 4
IN2	Average smoked per day	Less than 5 per day 5 – 9 per day 10-19 per day 20 or more per day	1 2 3 4
IN3 IN4	How many hours since you smoked your last cigarette? [Current and ex-smokers] For how many years have you smoked (or did you smoke) cigarettes?	Hours ago Years:	